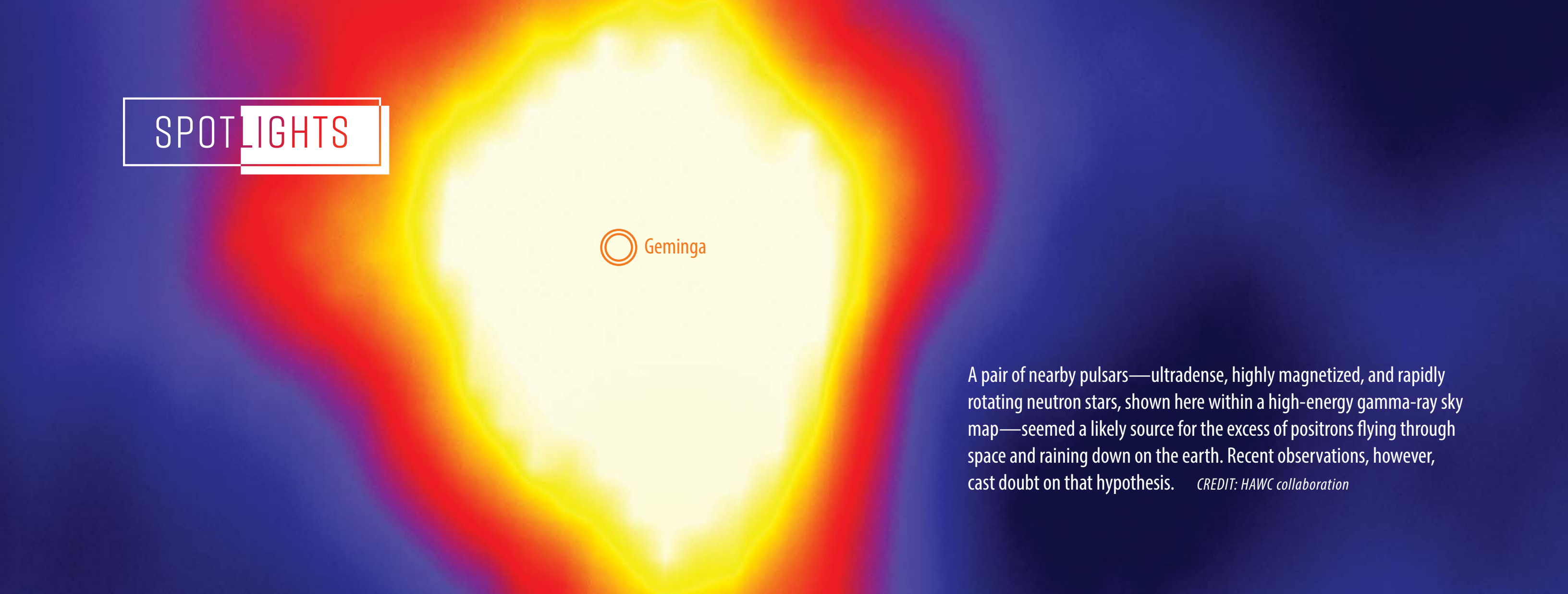

A pair of nearby pulsars—ultradense, highly magnetized, and rapidly rotating neutron stars, shown here within a high-energy gamma-ray sky map—seemed a likely source for the excess of positrons flying through space and raining down on the earth. Recent observations, however, cast doubt on that hypothesis. *CREDIT: HAWC collaboration*

ASTROPHYSICS

Positively Perplexing

Why are there so many positrons in our galactic neighborhood?

Ten years ago, scientists observed something unexpected: an excess of positrons among cosmic rays. Where they're coming from is a galactic mystery that endures to this day.

Cosmic rays are energetic particles, mostly protons and atomic nuclei, that zip about the galaxy and rain down on Earth. Electrons and positrons, matter-antimatter partners having the same mass but equal and opposite electrical charges, are less common. But positrons in particular are substantially over-represented relative to theoretical models of their production in interstellar space.

What is producing them? Whatever it is, it must be within about a thousand light years of Earth, about 1 percent of the diameter of the galaxy. Otherwise, they would have lost too much energy from interactions with interstellar radiation and magnetic fields to account for their measured abundance at energies of tens to hundreds of gigaelectron-volts.

Theorists have posited only a handful of possible sources. Perhaps the most likely, or at least the most straightforward to investigate, would be a collection of astrophysical objects that produce and accelerate positrons. This would include pulsars, supernovae, and micro-quasars; the most likely of these, researchers expected, would be pulsars.

Pulsars are the ultradense relics of massive stars that went supernova sometime in the past. They have extremely powerful and rapidly rotating magnetic fields capable of acting as particle accelerators, and there are good reasons to expect that many of the particles will be positrons. Such accelerated positrons would collide with the photons of microwave light that permeate the universe, causing the microwaves to increase in energy and become teraelectron-volt (TeV) gamma rays. By observing the gamma rays coming from around a pulsar, one can see whether or not the pulsar is a significant contributor to the positron excess.

"We measured the TeV gamma rays from two nearby pulsars, both old enough for the cosmic rays to have reached Earth," says Los Alamos scientist Brenda Dingus. The results come from more than 500 days of observation using the High-Altitude Water Cherenkov Observatory (HAWC), a world-class TeV cosmic- and gamma-ray observatory operated by a Los Alamos-led international team. "We found the TeV emissions and confirmed that positrons are indeed being produced there," says Dingus. "And the emissions extended out several degrees from each pulsar, allowing us to measure how fast the positrons move away from the pulsar." Assuming that movement is indicative of how the positrons would travel to Earth, the HAWC team calculated the spectrum of positrons expected to be observable here.

The calculations revealed that the lower-energy positrons don't make it very far due to scattering by turbulence in the surrounding magnetic field, and the higher-energy positrons do not live long enough due to energy losses when interacting with the magnetic field. As a result, only positrons at a sweet-spot energy around 1 TeV could reach Earth—and not very many of them. But the observed positrons are numerous and span a range of energies lower than a TeV. It's just not a match. Unless positron propagation between the source and the earth is markedly different than anticipated for some unknown reason, pulsars are not the source. Or if they are, then they must be both nearby and, as yet, undiscovered.

The trouble is, if pulsars are wrong, then what is right? Alternative astrophysical objects—supernovae and micro-quasars—are still possible, even though the former are brief and the latter are rare. And it is always possible that there could be some completely unknown process of cosmic-ray propagation that generates the positrons. The only other significant possibility, according to theorists, would be dark matter as the source. If dark matter is made of a swarm of effectively invisible particles, then it's possible that the particles are susceptible either to decay, like a radioactive nucleus, or to collisions with one another. Either process would likely produce positrons. In that case, the source is effectively all around. Nothing in the HAWC data prohibits this.

The HAWC study helps chip away at an astrophysical mystery, but for the time being, the positron-excess anomaly and the search for a source—whether somewhere or everywhere—lives on. LDRD

—Craig Tyler